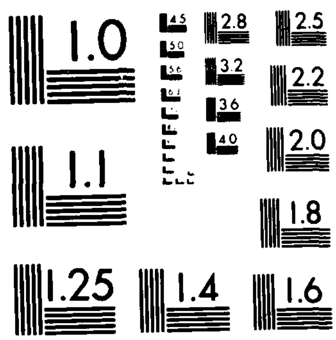
AD-A153 623 COLLISION AVOIDANCE FOR NAVAL TRAINING AIRCRAFT(U) 1/1
MASSACHUSETTS INST OF TECH LEXINGTON LINCOLN LAB
J W ANDREWS ET AL. 08 MAR 85 ATC-125 DOR/FAA/PM-84/4
UNCLASSIFIED F19628-85-C-0002 F/G 1/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(2)

Report No. DOT/FAA/PM-84/4

Project Report
ATC-125

Collision Avoidance for Naval Training Aircraft

J.W. Andrews
R.R. LaFrey
J.D. Welch

8 March 1985

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

Prepared for the Federal Aviation Administration.

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. DOT FAA PM-84 4	2. Government Accession No. AD-A153 623	3. Recipient's Catalog No.

4. Title and Subtitle Collision Avoidance For Naval Training Aircraft	5. Report Date 8 March 1985 6. Performing Organization Code
7. Author(s) John W. Andrews, Raymond R. LaFrey, Jerry D. Welch	8. Performing Organization Report No. ATC-125
9. Performing Organization Name and Address Massachusetts Institue of Technology Lincoln Laboratory P.O. Box 73 Lexington, MA 02173-0073	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-FA77WAI-817
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20591	13. Type of Report and Period Covered Project Report 14. Sponsoring Agency Code

15. Supplementary Notes

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, under Air Force Contract F19628-85-C-0002.

16. Abstract

Lincoln Laboratory was tasked by the FAA to assist the Naval Air Training Command in evaluating the feasibility of using the FAA's TCAS I concept as the document summarizes the results of a brief study and flight test activity conducted to that end. It begins with a review of Lincoln Laboratory's understanding of the nature of the mid-air collision problem at the Naval Air Training Center. This is followed by a brief analysis of a set of documented collisions and near-miss encounters involving aircraft of Navy Training Air Wing 5 at Whiting Naval Air Station in Florida in 1982 and 1983. Experience gained from FAA and Lincoln Laboratory flight tests of similar encounters is reviewed and applied to the Navy encounter data base. This is followed by a review of the results obtained when a Lincoln Laboratory aircraft equipped with a TCAS Experimental Unit (TEU) was flown to Whiting Field to evaluate the ability of TCAS I equipment to perform reliable surveillance in the Naval training environment. Flight test results show that the environment is quite unlike typical civil environments, but that the TCAS surveillance design would be capable of providing a significant degree of protection to Naval trainers.

17. Key Words Collision Avoidance Navy TCAS Training	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virgina 22161.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 40	22. Price

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

COLLISION AVOIDANCE FOR NAVAL TRAINING AIRCRAFT

Lincoln Laboratory was tasked by the FAA to assist the Naval Air Training Command in evaluating the feasibility of using the FAA's TCAS I concept as the basis of a collision avoidance system for Naval training aircraft. This document summarizes the results of a brief study and flight test activity conducted to that end. It begins with a review of Lincoln Laboratory's understanding of the nature of the mid-air collision problem ~~at~~ the Naval Air Training Center. This is followed by a brief analysis of a set of documented collisions and near-miss encounters involving aircraft of Navy Training Air Wing 5 at Whiting Naval Air Station in Florida in 1982 and 1983. Experience gained from FAA and Lincoln Laboratory flight tests of similar encounters is reviewed and applied to the Navy encounter data base. This is followed by review of the results obtained when a Lincoln Laboratory aircraft equipped with a TCAS Experimental Unit (TEU) was flown to Whiting Field to evaluate the ability of TCAS I equipment to perform reliable surveillance in the Naval training environment. Flight test results show that the environment is quite unlike typical civil environments, but that the TCAS surveillance design would be capable of providing a significant degree of protection to Naval trainers.

THE NAVY TRAINING COMMAND COLLISION PROBLEM

The salient characteristics of the Naval Air Training Command collision problem are as follows. Most of the documented collision and near misses occurred in relatively high density airspace, that is, airspace that exceeds the capabilities of most simple types of proximity warning and collision avoidance devices. Hazardous encounters almost exclusively occur in visual meteorological conditions with the Navy trainers flying under visual flight rules. A significant fraction of the encounters involve civil aircraft since the principal training area is not restricted to military traffic.

The aircraft types studied by Lincoln Laboratory were the T-34C fixed-wing trainer and the TH-57 helicopter. These aircraft appear to be involved in the majority of the hazardous encounters reported by Naval Air Training personnel.

Any collision avoidance device chosen for this fleet will be subject to severe cost constraints since it is a large fleet and the budget for avionics improvements for trainers is limited.

Cockpit space is somewhat limited both in panel area and panel depth, so that pilot interfaces must be efficiently packaged. There is a mild weight and balance problem with the T-34C aircraft, although there seems to be sufficient space for locating additional avionics devices, antennas and cabling.

THE NAVY TRAINING COMMAND COLLISION PROBLEM

* AIRSPACE
  - HIGH TRAFFIC DENSITY
  - VISUAL FLIGHT RULES
  - MIXED NAVY AND CIVILIAN TRAFFIC
* PRINCIPAL AIRCRAFT
  - T-34C
  - TH-57
* PRACTICAL CONSIDERATIONS
  - LOW-COST SOLUTION REQUIRED
  - COCKPIT SPACE LIMITED
  - WEIGHT AND BALANCE CONSTRAINED

LINCOLN LABORATORY MISSION TO WHITING

A contingent of Lincoln Laboratory personnel visited the Naval Air Station at Whiting Field the second week of November 1983 to obtain a first-hand assessment of the collision problem and the conditions under which a collision avoidance system for Navy trainers would have to operate. Several distinct activities were carried out during and after this trip. A data base of 31 encounters including hazardous near mid-air collisions and three fatal encounters was abstracted from records collected by Naval Training Air Wing 5 at Whiting Field.

A Lincoln Laboratory aircraft equipped with a TCAS Experimental Unit was flown to Whiting Field and participated in typical training maneuvers with Naval Flight instructors as copilots. This aircraft made complete recordings of the airborne transponder interrogation and reply environment for subsequent analysis. These recordings occurred over a period of approximately eight hours, and included periods that Naval personnel judged to be characteristic of the highest aircraft densities to be expected in the training area.

Lincoln personnel inspected the T34-C and TH-57 aircraft for potential installation and antenna shielding problems.

The visit was followed by an analysis of the Training Air Wing 5 encounter data base, an analysis of the traffic environment recorded by the TCAS Experimental Unit, and a study of the expected surveillance performance of an appropriate TCAS design in the training environment.

LINCOLN LAB MISSION TO WHITING

(7 - 16 NOV 1983)

* REVIEWED DATA BASE OF ENCOUNTERS
* RECORDED TCAS PERFORMANCE IN NAVAL TRAINING ENVIRONMENT
* INSPECTED TRAINING AIRCRAFT FOR INSTALLATION PROBLEMS
* FOLLOWED WITH ANALYSES OF:
  - ENCOUNTER DATA BASE
  - TCAS SURVEILLANCE PERFORMANCE

ENCOUNTER DATA BASE ANALYSIS

The 31 encounters that were analyzed all occurred in 1982 and 1983. The non-fatal encounters occurred between January 1983 and the date of the Lincoln visit. In order to obtain more data on fatal encounters, the fatal encounters from 1982 were also included in the data base. All of the encounters occurred in the Whiting Field training area. The three that were fatal all involved pairs of T-34Cs. One of the fatal encounters did not involve an actual collision, but rather a near collision which induced a severe maneuver leading to a low-altitude stall and subsequent crash.

Nineteen of the encounters involved pairs of T-34Cs. Twelve of the encounters involved civil aircraft. Of those civil aircraft, only four were light single-engine aircraft of a type that might not be equipped with altitude-reporting transponders. The other eight were all either twins or jets and were most likely equipped for altitude reporting. The four encounters involving TH-57s were all with non-jet-transport civil aircraft. There was one encounter between a T-34C and a jet transport aircraft.

The maximum closing speed estimated for the 31 encounters was about 390 kt. The most commonly reported closing speed was about 200 kt. Most of the encounters occurred such that the intruder was within the field of view of the trainer pilot. (The next page provides detailed distributions for these statistics.)

The probable cause for most of the hazardous incidents was failure of the trainer pilot to see the other aircraft in time. In some cases, this failure occurred because of the presence of other traffic. In one case, there was an apparent misunderstanding between the pilot and the ground controller. In at least one of the incidents the pilot failed to visually clear the local airspace prior to initiating an aerobatic maneuver. In general, it appears that reliance on unaided visual search to detect the presence of nearby hazardous aircraft is often ineffective in the Naval Air training environment. The unexpected nature of encounters with civil aircraft may be a factor in this breakdown. Among factors that do not appear to be significant, are weather, high closing speeds, or equipment malfunctions.

It is significant in the context of automatic collision avoidance equipment that a large fraction of the encounters occurred in airspace where there were multiple aircraft within visual range. This implies that a simple proximity warning would not be enough. The pilot must be assisted in identifying and sorting out multiple aircraft and, if possible, in determining which aircraft is the most threatening at any instant.

ENCOUNTER DATA BASE ANALYSIS

* 31 ENCOUNTERS (TRAINING AIR WING 5)

  28 NEAR MISSES FROM JANUARY TO NOVEMBER 1983
  3 FATAL ACCIDENTS IN 1982 AND 1983

* AIRCRAFT TYPES

  19 ENCOUNTERS WERE BETWEEN PAIRS OF T-34s
  12 WITH CIVIL AIRCRAFT, LIKELY WITH TRANSPONDERS

* CLOSING SPEEDS

  MAXIMUM WAS 390 KT, MOST WERE 200 KT

* APPROACH BEARINGS

  MOST WERE WITHIN PILOT FIELD OF VIEW

* CAUSES OF ENCOUNTERS

  OTHER AIRCRAFT NOT SEEN
  PILOT NOT AWARE OF MULTIPLE AIRCRAFT
  MISUNDERSTANDING WITH GROUND ATC
  AEROBATIC MANEUVERS

* TRAFFIC ENVIRONMENT OF ENCOUNTERS

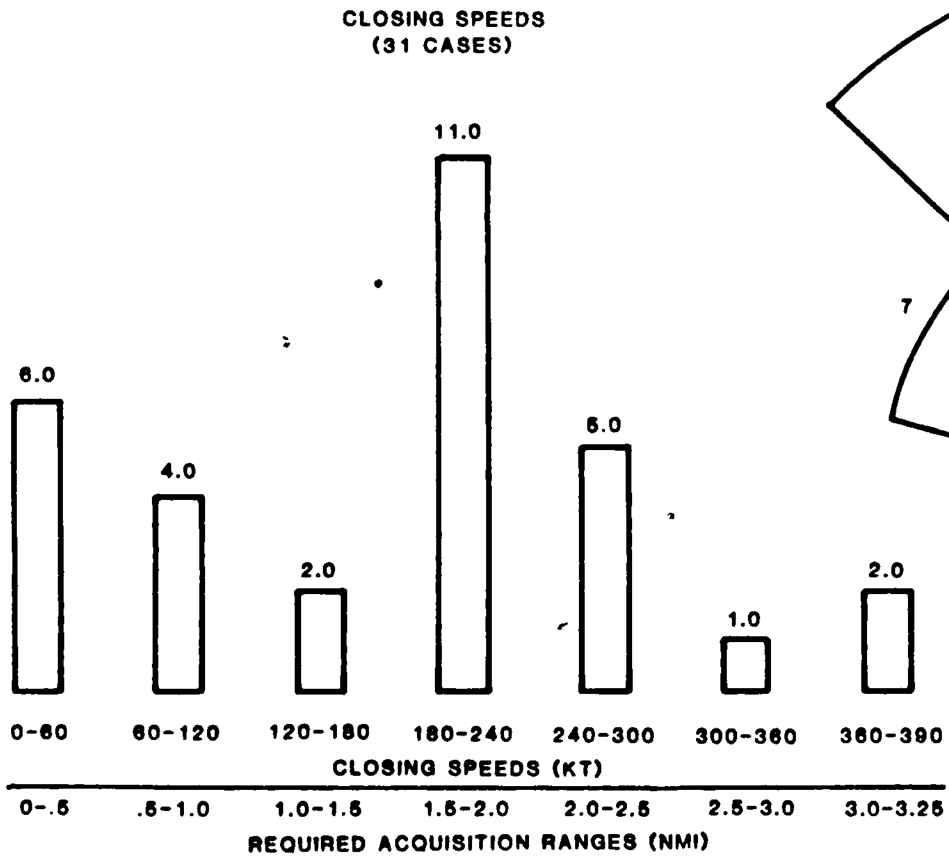
  MANY INVOLVED MULTIPLE AIRCRAFT WITHIN VISUAL RANGE

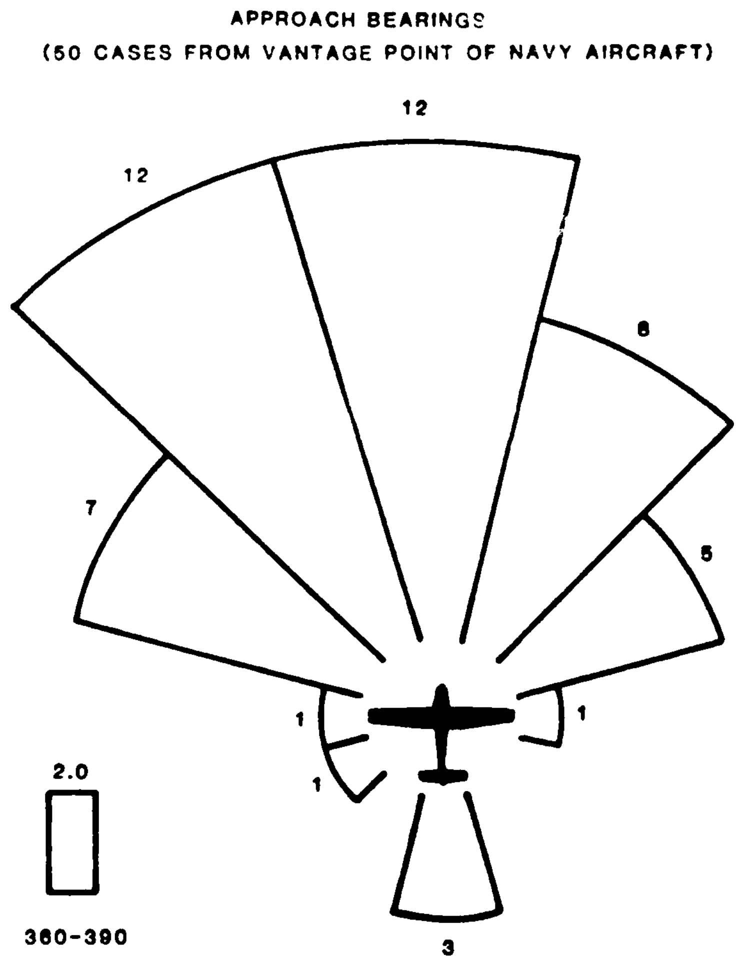
DISTRIBUTION OF ENCOUNTER CLOSING SPEEDS AND BEARINGS

The distributions of the approximate closing speeds and approach bearings of the 31 encounters are shown. The required surveillance detection range for a 30-second warning time is also shown for each value of closing speed in the histogram. A maximum detection range of 3.5 nmi would have been adequate for each of the 31 cases studied.

The distributions of approach bearings for the detected aircraft are also shown from the vantage point of the 50 Navy aircraft involved in the 31 encounters. It is seen that only three of the approaching aircraft would have been outside of the normal field of view of the crew.

DISTRIBUTION OF ENCOUNTER CLOSING SPEEDS & BEARINGS





FATAL ENCOUNTERS

A closer look at the three fatal encounters shows that the approximate closing speeds ranged from 200 kt to 320 kt. As well as can be determined, the three encounters occurred enroute between home base and the training area at an altitude of 8500 ft, near one of the training airfields at an altitude of 3500 ft, and in a landing pattern at one of the training fields. It appears that pilot workload was a significant factor in each of the fatal encounters. That is, in each case, one or both of the pilots was involved in some intensive activity which focused his attention inside the cockpit. In the encounter that occurred in the landing pattern one of the pilots was attempting to merge into the downwind sequence behind another aircraft and was not aware of the presence of the third (conflicting) aircraft already in the pattern.

FATAL ENCOUNTERS

* THREE FATAL ENCOUNTERS OCCURRED IN 1982-83
* AIRCRAFT INVOLVED: ALL T-34C
* CLOSING RATES: 200 KT, 230 KT, 320 KT
* PHASE OF FLIGHT:
  - ENROUTE (8500 FT)
  - NEAR AIRFIELD (3500 FT)
  - LANDING PATTERN (900 FT)
* HIGH WORKLOAD IN ALL THREE
* UNAWARENESS OF ALL TRAFFIC MAJOR FACTOR IN ONE

EXPERIENCE FROM FAA/LINCOLN TCAS FLIGHT TESTS

At this point it is appropriate to interject some relevant observations based on experience obtained in an extensive series of live flight tests involving encounters staged to measure pilot reactions to TCAS traffic advisories. These tests have been conducted for the FAA using TCAS equipment installed both in FAA 727 flight test aircraft and in a Lincoln Laboratory Cessna 421 twin. Some of the relevant conclusions from these tests are as follows:

TCAS traffic advisories are very useful in locating hazardous VFR aircraft out to ranges of three or four nmi. At greater ranges it becomes difficult to see small aircraft and the effectiveness of a traffic advisory diminishes.

Traffic advisories that include bearing information significantly decrease the time required for the pilot to locate the target. Bearing information is useful in sorting out multiple targets when there are more than one present within the pilot's visual range. Bearing information is also useful in distinguishing targets so that they can individually be assigned symbolic priority levels. Priority coding of traffic helps to identify the immediate collision threat in the presence of less urgent nearby traffic.

Analysis of visual acquisition statistics from airborne encounters allows an estimate of the effectiveness of TCAS in reducing the collision hazard for Navy trainers. The results indicate that timely detection would have occurred in about 95% of the cases studied if TCAS traffic advisory capability has been available on all the Navy trainers. As a result, a hazardous or fatal situation would have been converted into a safe or routine encounter.

EXPERIENCE FROM FAA/LINCOLN TCAS FLIGHT TESTS

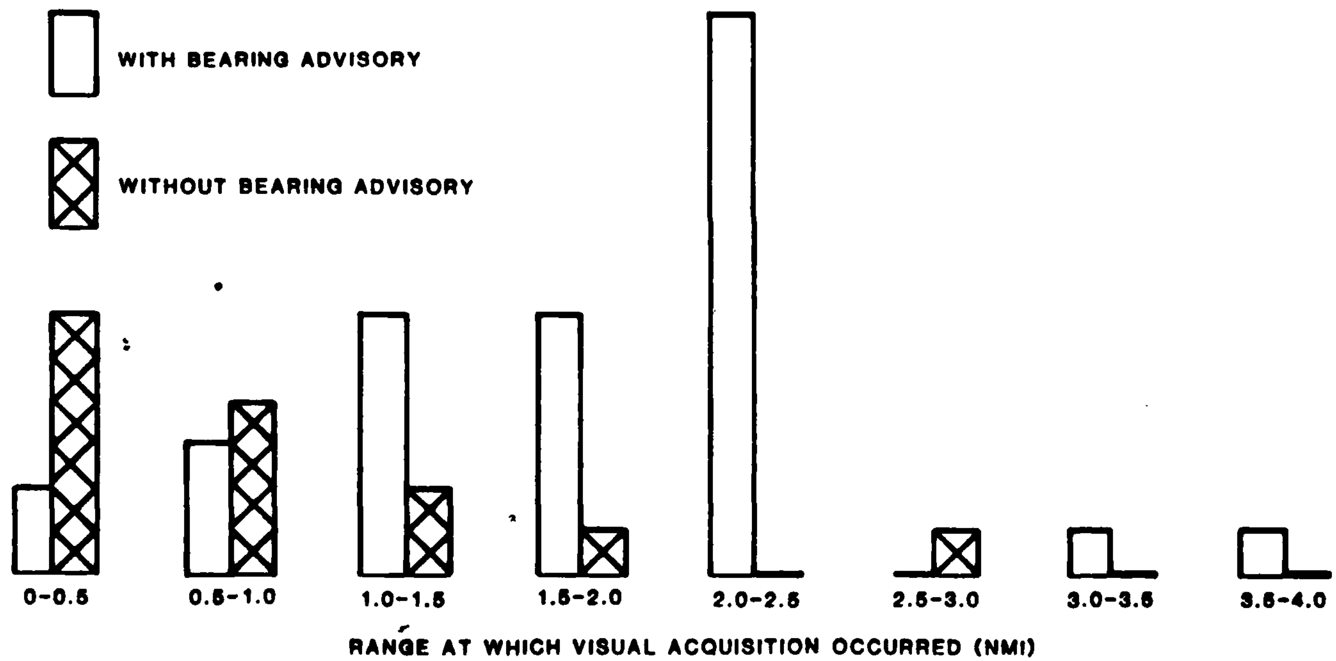
* TRAFFIC ADVISORIES:
  - ARE VERY EFFECTIVE IN VFR ENCOUNTERS
  - ARE APPROPRIATE FOR AIRCRAFT OUT TO 3 OR 4 NMI
  - CAN ALSO PROVIDE INFORMATION ON TARGET PRIORITIES
* TRAFFIC ADVISORIES WITH BEARING INFORMATION
  - DECREASE TIME TO LOCATE 1 AIRCRAFT BY FACTOR OF 6 OR 7
  - ARE ESSENTIAL FOR LOCATING MORE THAN 1 AIRCRAFT
* TIMELY DETECTION ESTIMATED IN 95% OF NAVY CASES IF:
  - TCAS ADVISORIES HAD BEEN AVAILABLE

100295

VISUAL ACQUISITION RANGES

A number of flights were conducted at Lincoln Laboratory to determine if the inclusion of bearing in a traffic advisory has a significant effect on the average range at which an intruder is visually detected by the pilot. The results plotted here for a total of 47 encounters show the distribution of detection ranges for encounters with and without bearing. It is evident from the distribution that the acquisition ranges are significantly increased by the availability of bearing information.

VISUAL ACQUISITION RANGES

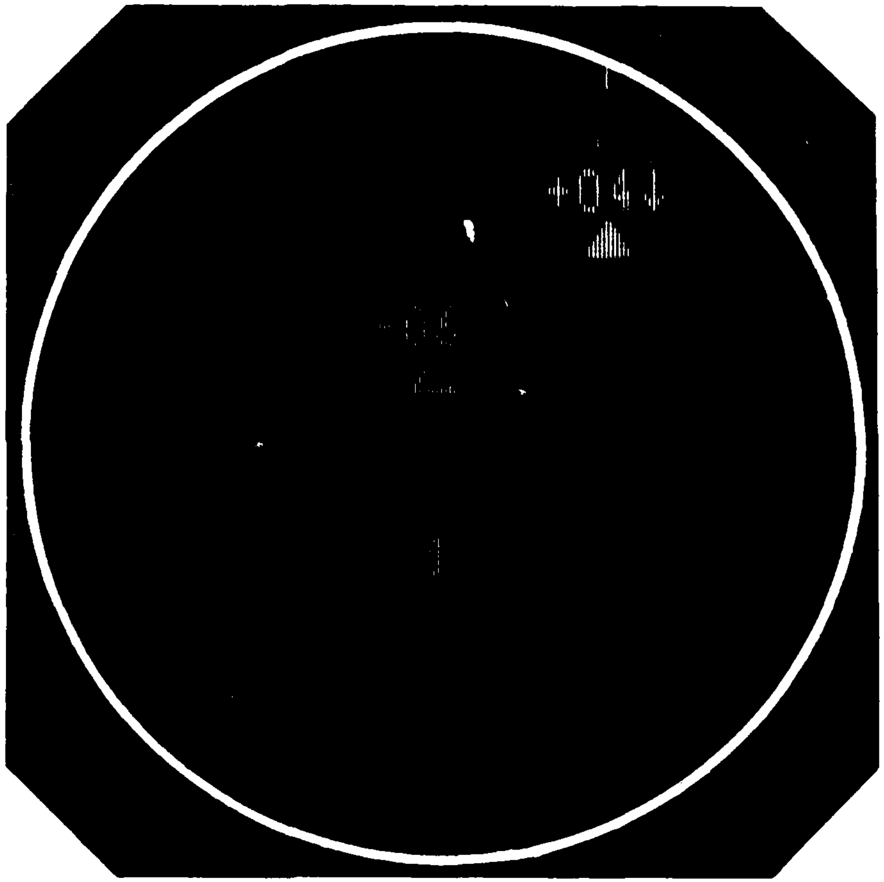


EXAMPLE OF TRAFFIC ADVISORY DISPLAY

This is a photograph of a plan-position format for providing TCAS traffic advisories to the pilot on a monochrome display. Own aircraft is shown at the center of a two-nautical-mile radius range ring. Potentially conflicting aircraft are displayed by open triangle symbols accompanied by altitude tags. The aircraft at a bearing of 12 o'clock and a range of about 1.5 nmi is 600 ft below own aircraft. Higher-priority threatening aircraft (with predicted times to closest approach of less than 25 seconds) are displayed as solid triangles. The aircraft shown 400 ft above own aircraft and descending represents a higher priority threat in this example even though its current range is greater than that of the other aircraft.

A display of this sort can be realized by means of a number of available display technologies and can be readily fit into a standard cockpit instrument space.

EXAMPLE OF TRAFFIC ADVISORY DISPLAY



RECOMMENDATIONS FROM ENCOUNTER DATA BASE ANALYSIS

Consideration of the information derived from analysis of the 31 encounters in the Naval training data base as well as experience from airborne flight tests leads to several conclusions.

First, since a significant fraction of the hazardous encounters involve civil aircraft, it is highly desirable that the collision avoidance system for the Navy trainers have the capability to detect and provide protection against civil aircraft. Since most civil aircraft that conflict with Navy trainers will have transponders with encoding altimeters, a collision avoidance system that operates by detecting civil transponders would be adequate in this regard. Such a system could also alert the pilot to the presence of aircraft with non-altitude-reporting transponders.

Second, it is important that the collision avoidance system provide a reliable surveillance range of about 3.5 nmi. Greater detection ranges would increase the cost of the equipment while providing little additional collision avoidance benefit. Lesser detection ranges would not protect against head-on encounters between T-34Cs.

Third, some sort of plan-position display including range, bearing, and altitude is recommended because there is a high incidence of multiple-aircraft encounters in the training environment. Such a display facilitates the visual detection of traffic by the pilot and helps him to distinguish between aircraft. Furthermore, as shown in the previous figure, it is a simple matter to code the display to clearly indicate which of the targets is most threatening.

Finally, the analysis of the data on the 31 encounters provided to Lincoln Laboratory indicates that there is less need for a collision avoidance device for the TH-57 helicopter. A decision to equip the TH-57 should be based on review of a larger body of encounter data.

RECOMMENDATIONS FROM ENCOUNTER DATA BASE ANALYSIS

* NAVY CAS SHOULD DETECT ALL TRANSPONDER-EQUIPPED AIRCRAFT

* SURVEILLANCE RANGE OF 3.5 NMI IS APPROPRIATE FOR T-34C

* PLAN-POSITION DISPLAY IS NECESSARY:
  - TO SORT OUT MULTI-AIRCRAFT ENCOUNTERS
  - TO SPEED VISUAL DETECTION
  - TO PROVIDE TARGET PRIORITY INFORMATION

* ENCOUNTER DATA SHOWS LESS NEED FOR TCAS IN TH-57

TCAS PERFORMANCE IN NAVAL TRAINING ENVIRONMENT

In order to assess the applicability of the FAA's TCAS concept to the Naval Air Training environment, about 8 hours of flight test data were recorded in the Whiting Field area with an instrumented TCAS Experimental unit. In those eight hours of flying, there were some periods in which no aircraft were detected near the test aircraft. At other times up to 11 other aircraft were in track simultaneously. In all, about 50,000 track-seconds of data were recorded for aircraft within 3.5 nmi and 3000 ft of the TCAS aircraft.

One concern about the use of a civil collision avoidance design for military aircraft was that the nature of the target tracks would be very different because of the higher accelerations employed in military training maneuvers. Post-flight analysis of this data indicated that the overall probability of successfully tracking targets within 3.5 nmi and ± 3000 ft was 93% using peak transmit powers of about 60 Watts. The probability of establishing a false track on the basis of erroneous range or altitude data was less than 1%.

TCAS PERFORMANCE IN NAVAL TRAINING ENVIRONMENT

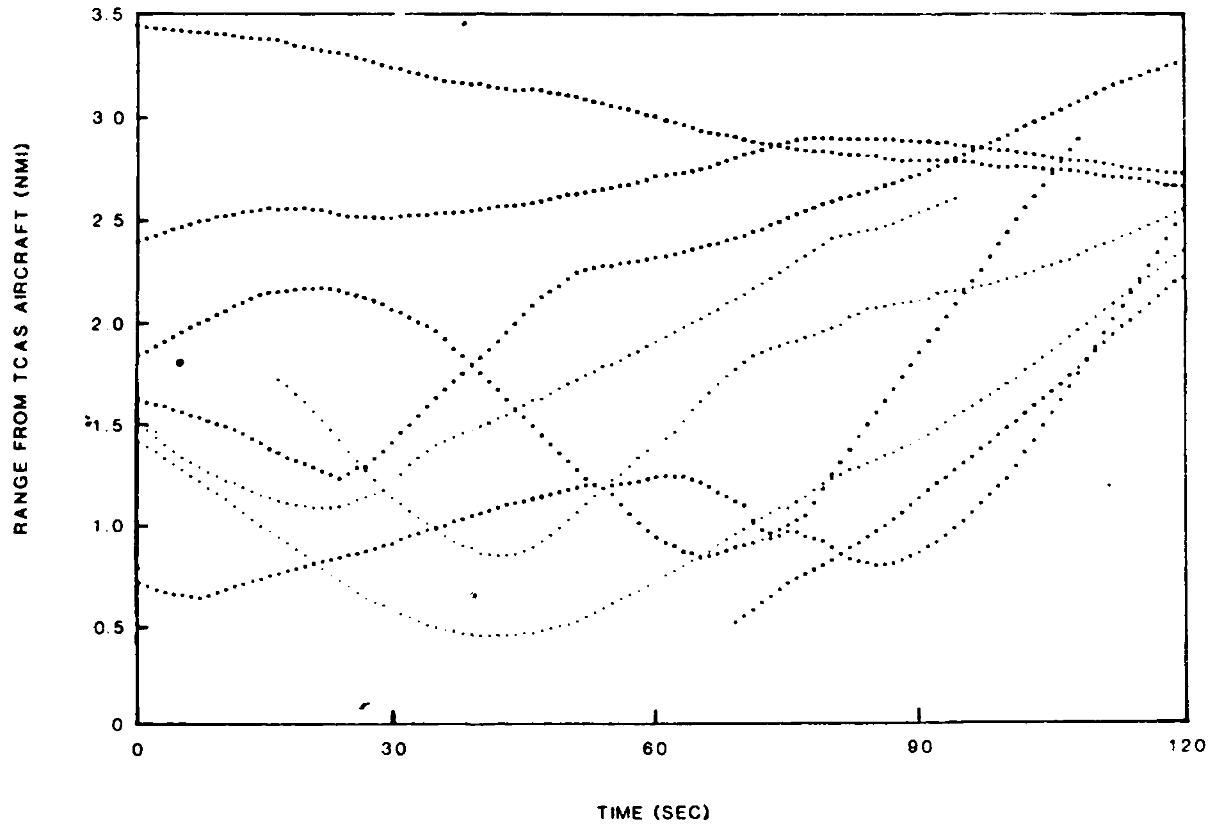
* DATABASE:
  8 HRS OF FLIGHT TIME
  50,000 SECS OF TRACKS WITHIN 3.5 NMI AND +/-3000 FT.
* PEAK OBSERVED TRAFFIC DENSITY
  11 AIRCRAFT WITHIN 3.5 NMI
* PROBABILITY OF SUCCESSFUL SURVEILLANCE TRACK:
  93%
* PROBABILITY OF FALSE TRACK:
  LESS THAN 1%

TCAS FLIGHT TEST AT WHITING FIELD

This is an example of data from the Whiting Field area on 9 November 1983. This plot shows the range versus time of all of the tracked aircraft out to 3.5 nmi within a 2-minute time period. Between 70 and 90 seconds there are a total of 9 aircraft in track. Once each track has started, the tracking is perfect within this 2-minute interval. There are no holes or apparent false tracks. It is evident from this data that many of the targets were executing relatively severe maneuvers. Typical range trajectories for civil aircraft appear as nearly ideal parabolas as the detected aircraft flies past the TCAS aircraft. An example of such a trajectory is the one that passed within about 0.5 nmi at about 40-seconds into this plot. In civil airspace one seldom sees a trajectory showing an increase in range followed by a period of decreasing range. Yet such trajectories appear repeatedly in the Whiting Field data, indicating that the tracked aircraft were maneuvering with high accelerations. Although the tracker design used in the TCAS equipment was not optimized for such trajectories, it was found that in almost all instances the TCAS tracker was able to follow the accelerations of the military aircraft. The only consistent failure occurred when the tracked aircraft's vertical rate exceeded 6000 ft/min. This limitation can be easily corrected by a minor parameter change in the TCAS tracker altitude correlation windows.

TCAS FLIGHT TEST AT WHITING FIELD
(9 NOV 1983)

TARGET RANGES vs TIME IN HIGH-DENSITY AIRSPACE



PROPOSED AVERAGE POWER LIMITS FOR TCAS I

There are two distinct categories of TCAS equipment. TCAS II, which is intended for use in air carrier aircraft, provides resolution advisories to the pilot and therefore includes Mode S air-to-air data link capability for coordinating maneuvers with other TCAS II aircraft. TCAS I, which is intended for general aviation aircraft, provides only traffic advisory information to the pilot and therefore does not include Mode S capability as an essential requirement. TCAS I seems more appropriate for Navy trainers than TCAS II.

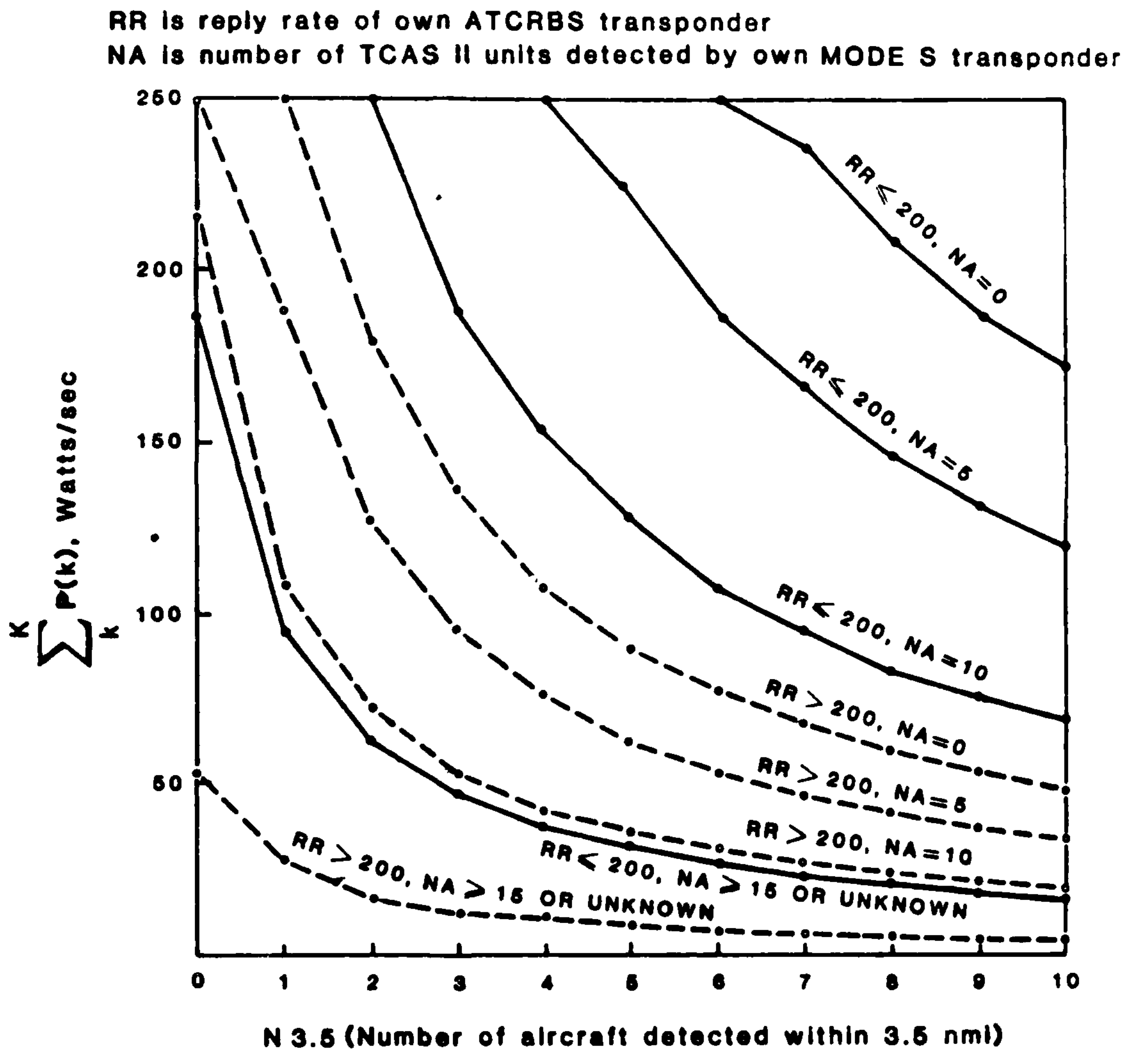
All TCAS transmitters must limit their transmitted power in high-density areas to maintain a low probability of interference with Air Traffic Control surveillance. The methods for doing this are different in the two categories of equipment because TCAS I is less complex, does not have as complete a capability for monitoring the local environment, and has no means for announcing its presence to other TCAS units in the area.

As currently defined by the RTCA TCAS I Functional Guidelines (RTCA DO/184, May 1983), a TCAS I device is permitted to transmit no more than the equivalent of a single 5-Watt peak power interrogation each second. Such a limit is adequate for a system whose sole function is to present a warning to the pilot that there is at least one nearby aircraft at very short range (less than two miles), but it is inadequate for reliably supporting a plan-position display of multiple aircraft out to ranges of 3.5 nmi.

A proposal is under consideration by RTCA to allow a TCAS I unit to transmit more than one 5-Watt interrogation each second if its knowledge of the local transponder environment indicates that no significant interference will result. The TCAS I unit can avail itself of three types of information to accomplish this: a) its knowledge of the local density of transponder-equipped aircraft, which can be estimated by counting the number, N(3.5), of aircraft within a 3.5 nmi radius b) its knowledge of the local interrogation environment obtainable by monitoring the reply rate (RR) of own ATCRBS transponder, and c) its knowledge of the number (NA) of TCAS II-equipped aircraft in the vicinity obtainable automatically by monitoring TCAS II transmissions received by an on-board Mode S transponder.

The accompanying graph shows the peak power allowed each second under the proposed new rules for various combinations of N(3.5), RR, and NA. For example, if RR is greater than 200 ATCRBS replies per second from own transponder, but there are no TCAS II units detected (NA=0), the TCAS I would be allowed to transmit any combination of interrogations whose peak powers add up to less than 50 Watts each second regardless of the number of transponders detected within 3.5 nmi. And if N(3.5) is less than two, the TCAS I can transmit up to 250 Watts each second.

PROPOSED AVERAGE POWER LIMITS FOR TCAS I

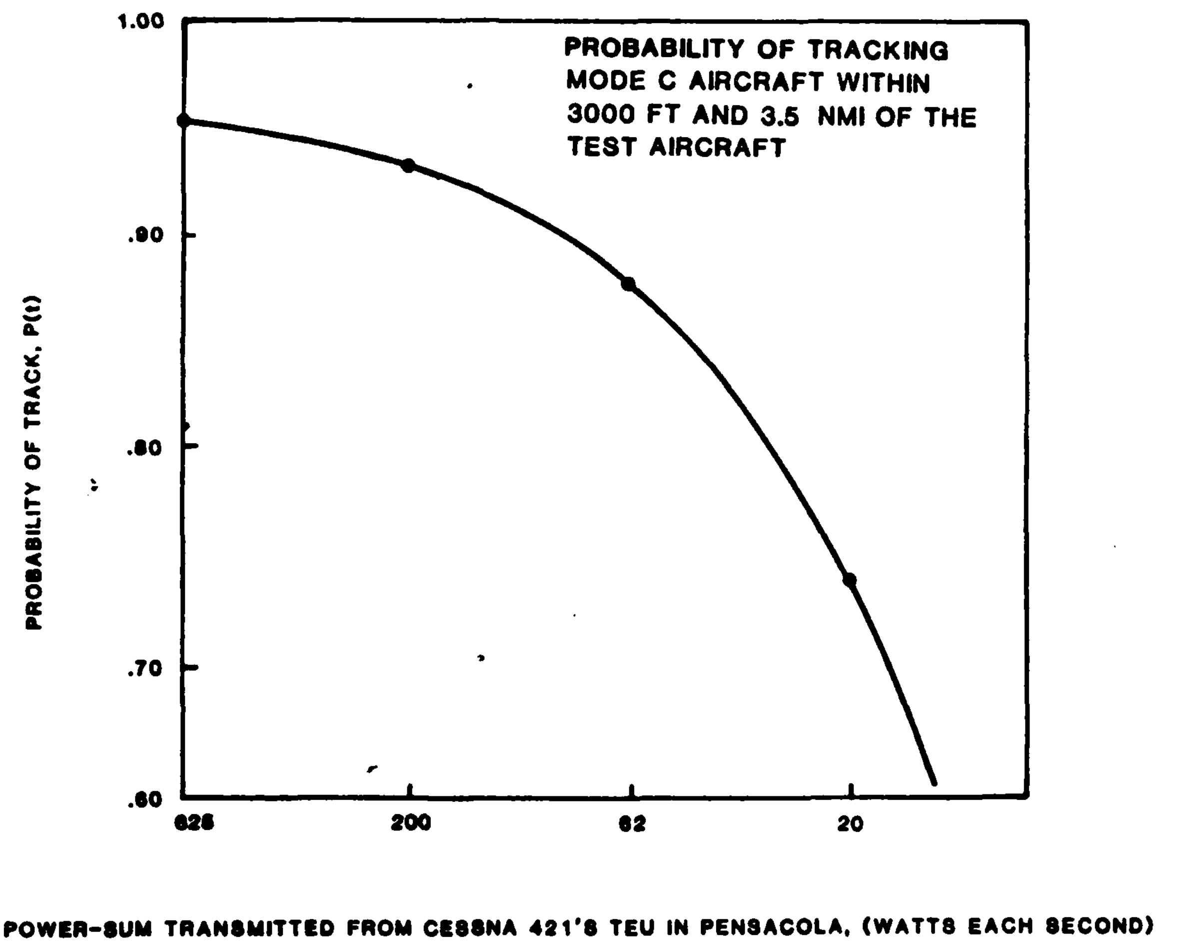


100294

PERFORMANCE OF TCAS AS A FUNCTION OF TRANSMIT POWER

The TCAS experimental unit that was flown to Whiting Field transmitted a sequence of interrogations of descending power each second and recorded the replies elicited by each of these interrogations. Each of these interrogations was preceded by a lower-power suppression pulse to limit the number of transponders that replied to it. This scheme is known as "whisper-shout" and enables TCAS to separate multiple targets so that their replies do not overlap and garble each other. Because of this sequence, it was possible, by post-flight analysis of the data, to simulate a TCAS unit of peak transmit power ranging from that of a TCAS II to that of a low power TCAS I. The accompanying figure compares the track probability of the TEU when operating at the minimum transmit power characteristic of *TCAS II equipment (a peak power of approximately* 125 W and an interrogation power-sum of 625 Watts each second) with the performance when operating with power-sums of 200, 62, and 20 Watts each second. In deriving the probability of track for this plot, the estimate of the true presence of a target was based on a manual analysis of all of the replies received from that target. It is seen that the overall probability of track was not strongly affected by the transmit power until the power-sum was reduced below about 100 Watts each second. Thus, a design that complies with the proposed guidelines for TCAS I could provide adequate performance in the Whiting Field environment provided that NA, the number of TCAS II units in the area, is small enough so that the interrogation power can be increased to 100 Watts each second. This requires a means of monitoring NA. Monitoring can either be accomplished by setting NA to a fixed value that is certain to not be exceeded in the training airspace or by including a Mode S transponder as part of the TCAS I installation.

PERFORMANCE OF TCAS AS A FUNCTION OF TRANSMIT POWER



100[illegible]

PROPOSED DESIGN FOR NAVY TCAS

An example of a design that is consistent with the proposed new interference limiting guidelines is the following:

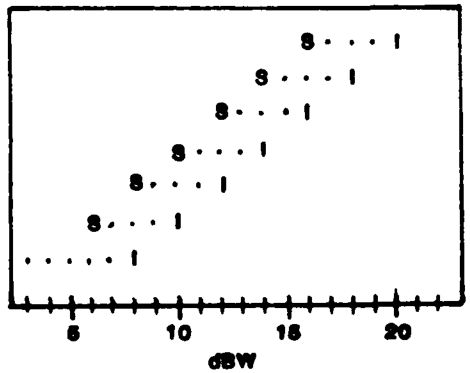
The design would include a bearing estimation capability and would provide traffic advisories on nearby transponder-equipped aircraft (both ATCRBS and Mode S). It would not generate resolution advisories. It would not transmit Mode S interrogations, but it would be capable of receiving Mode S broadcasts on 1090 MHz from nearby TCAS II-equipped aircraft as part of its interference limiting function. It would determine the reply rate of the on-board ATCRBS transponder by monitoring the activity of the mutual suppression line. It would include a 100-W peak power transmitter with eight discrete power levels enabling it to generate a 7-level whisper-shout sequence as shown in the figure.

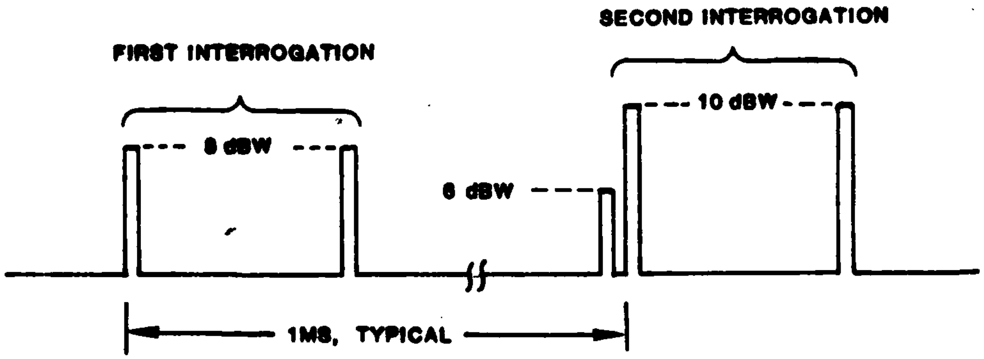
In light interference environments it would transmit this sequence once each second. If the interference environment were to increase and it was forced to cut back on its average power as shown on p. 25, it would first decrease its interrogation rate and then decrease its peak power by sequentially eliminating the highest power steps of the whisper-shout sequence. Eventually, in the heaviest interference environments it would transmit only the lowest three levels of this sequence once every six seconds.

When transmitting the full 7-level sequence it is estimated that it could provide traffic advisories on transponders out to 3.5 nmi with at least 90% reliability into traffic densities of at least 0.1 aircraft per square nautical mile. When transmitting the lowest level sequence it would conform to the original TCAS I interference limiting guidelines that permit an average power of 5 watts each second, yet it would be capable of detecting targets out to approximately 2 nmi in densities of 0.07 aircraft per square nautical mile.

PROPOSED DESIGN FOR NAVY TCAS
(WHISPER -SHOUT SEQUENCE)

STEP NUMBER	INTERROGATION POWER (dBW)	SUPPRESSION POWER (dBW)
7	20	16
6	18	14
5	16	12
4	14	10
3	12	8
2	10	6
1	8	NONE





100111A

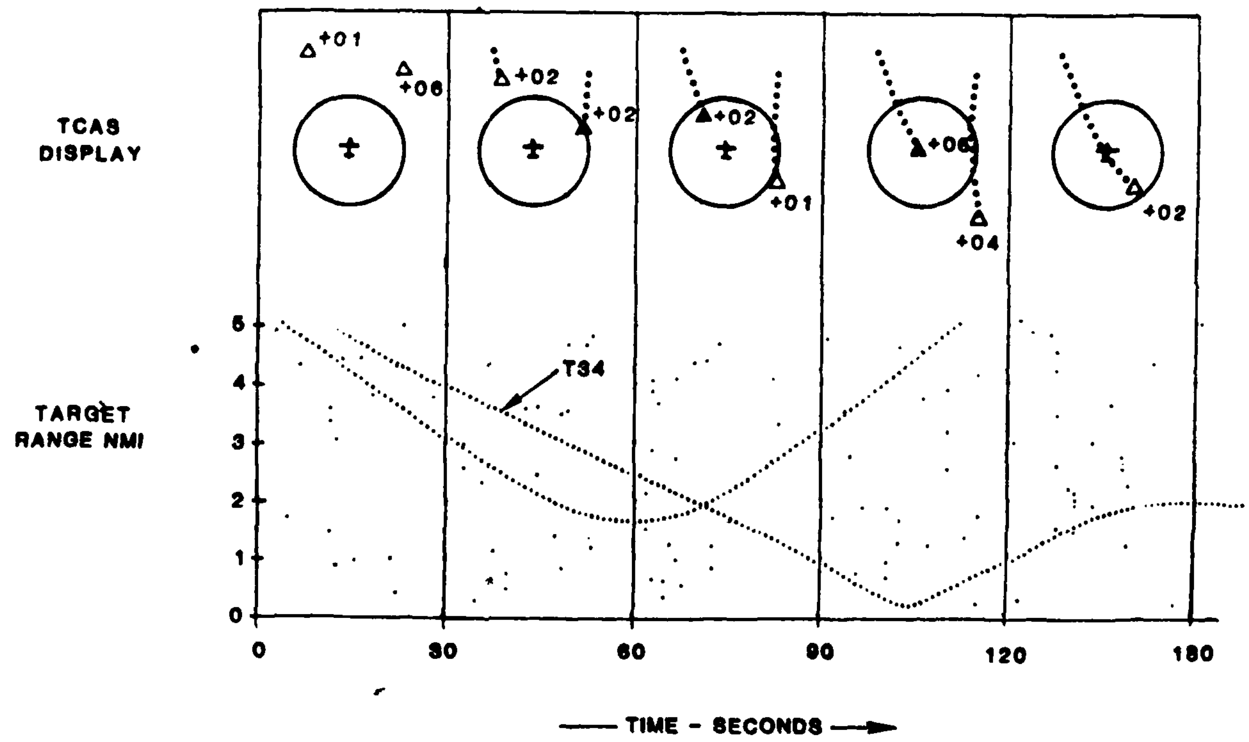
C421 - T34 ENCOUNTER

An example of the utility of TCAS is illustrated in this figure which recorded an unintentional encounter between the Lincoln Laboratory Cessna 421, a Navy T-34C, and another unidentified aircraft. This figure shows range trajectories and plan-position snapshots as they appeared on the TCAS display as the encounter unfolded. The first target appeared on the TCAS display at about 1 o'clock at an altitude 600 ft above. This aircraft passed about 2 nmi off to the right and briefly triggered a traffic alert as shown by the solid triangle in the second snapshot.

The second aircraft, a T-34C, appeared about 10 seconds after the first. A traffic alert was triggered for the T-34C at time 75 sec (about 30-seconds before the time to closest approach) and the pilot of the Cessna 421, seeing the rapidly approaching T-34C, executed a descend maneuver to avoid a collision. The trainer passed overhead with an altitude difference of about 600 ft and a minimum slant range of about 1000 ft.

C-421 - T-34 ENCOUNTER

9 NOV '83 10:30 AM



AIRCRAFT INSTALLATION CONSTRAINTS

The final activity undertaken during the Lincoln Laboratory visit to Whiting Field was a physical inspection of the Navy Training aircraft. It was concluded that, although there appears to be adequate space for installation of TCAS electronics, displays, cabling, and antennas, a minor weight-and-balance adjustment may be necessary to accommodate the TCAS equipment.

There appears to be adequate panel area for TCAS displays in both the fore and aft cockpits of the T-34C and in the single cockpit of the TH-57. Panel depth for a traffic advisory display is somewhat limited, but should be adequate if a suitably shallow display is provided.

There is adequate physical space for mounting the TCAS antennas, which consist of a small, top-mounted, four-element array for direction-finding and a bottom-mounted monopole. However, the ground plane for the direction-finding antenna is not as large or as unobstructed as would be preferred. Before proceeding with a procurement, direction-finding performance should be verified by measurement using a test antenna mounted on the airframes of the training aircraft.

AIRCRAFT INSTALLATION CONSTRAINTS

(T-34C AND TH-57)

* SPACE FOR TCAS EQUIPMENT IS ADEQUATE
  WEIGHT AND BALANCE MAY BE A PROBLEM
* PANEL AREA FOR DISPLAYS IS ADEQUATE
  DEPTH FOR PPI DISPLAY IS LIMITED
* SPACE FOR ANTENNA EXISTS
  BEARING ESTIMATION PERFORMANCE MUST BE VALIDATED

SUMMARY

A review of selected midair collision statistics from the Naval Air Training Command indicates that the Traffic Alert and Collision Avoidance System (TCAS) recently developed by the FAA would be highly effective in reducing the incidence of midair collisions and dangerous encounters in the naval training environment.

Live flight testing of experimental TCAS equipment at Whiting Naval Air Station showed that equipment similar to the FAA's TCAS I category (intended for general aviation aircraft) would provide reliable surveillance of essentially all threatening aircraft in naval training airspace.

The recommended TCAS design would provide a surveillance range of 3.5 nmi and a target bearing estimation capability suitable for locating a target to within one clock position. The equipment should be capable of displaying multiple targets to the pilot on a plan-position display that is coded to provide an indication of target threat priority.

The T34-C and TH-57 training aircraft have adequate space for TCAS equipment and displays. However, the performance of the TCAS direction-finding antenna should be verified experimentally on the airframes of the training aircraft.

SUMMARY

TCAS WOULD REDUCE THE NUMBER OF NAVAL TRAINING MIDAIRS

TCAS SURVEILLANCE VALIDATED IN NAVAL TRAINING AREAS

TCAS FOR NAVAL TRAINERS SHOULD HAVE:

- 3.5 NMI RANGE
- MULTIPLE TARGET CAPABILITY
- PPI DISPLAY

TRAINING AIRCRAFT HAVE ADEQUATE SPACE FOR TCAS EQUIPMENT

TCAS ANTENNA PERFORMANCE SHOULD BE VERIFIED ON TRAINERS

END

FILMED

6-85

DTIC